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Magnetic Susceptibility
# of a
Group of Esters

by

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A Thesis Submitted for the Degree of
Bachelor of Arts

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Magnetic Susceptibility of a Group of Esters

The phenomenon of magnetization was discovered by the Ancients in Asia Minor, who found that a certain black stone possessed the power of attracting small pieces of iron. This stone was called lodestone. It was afterwards found that this lodestone was identical with the substance, known to Mineralogists, as Magnetite, having the chemical composition, Fe_3O_4.

This is nearly all that was known of the magnet until 1600, when Dr. Gilbert published his famous work De Magnete. As early as this, a distinction was made between magnets and magnetic substances. It was found in 1729, by Savery, that artificial magnets could be produced, and if suspended had the power of pointing North and South.

From the time of Gilbert to the nineteenth century, the magnet was studied with varying degrees of success by such men as Coulomb, Becquerel, Knight and others. In 1845 the subject of magnetism received a great impetus at the hands of Faraday who through classic researches showed that all substances were affected by the influence of a magnet. Faraday also arrived at the broad generalization that all bodies could be divided into two great classes; first, those which were attracted by a magnet, and second, those repelled. To these two classes of substances he gave the names paramagnetic and diamagnetic respectively.

This differentiation was founded upon the fact that those substances which he termed paramagnetic placed their long axes parallel in contradistinction to the diamagnetic ones which placed their long axes at right angles to the magnetic

field.

In making this classification, he found that some substances were more strongly paramagnetic than others, and some were more diamagnetic than others. With these facts in mind he proceeded to classify the substances of these two groups in the order of their paramagnetic and diamagnetic strengths.

The following is the result of this classification.

Paramagnetic	Diamagnetic
Iron	Bismuth
Nickle	Antimony
Cobalt	Zinc
Manganese	Tin
Chronium	Cadmium
Cerium	Sodium
Titanium	Mercury
Palladium	Lead
Platium	Silver
Osurium	Copper
	Gold
	Arsenic
	Uranium
	Rhodium
	Iridium
	Tungsten

Since the time of Faraday this classification has been enlarged notably by Pascal, who made a special study of inorganic salts. With these facts in mind it was suggested by Professor Terry to make a study of organic salts, particularly a

group of Esters.

A. Definitions:

The general definition of magnetic susceptibility is the ratio between the intensity of magnetization and the strength of the field, or,

$$\chi = \frac{I}{H}$$

where χ = Susceptibility

I = Intensity of magnetization

H = Field strength.

It is necessary here to distinguish between two susceptibilities according as intensity of magnetization is defined as magnetic moment per unit mass, or magnetic moment per unit volume, the former being called mass susceptibility I_m and the latter, volume susceptibility I_v.

By definition

$$I_m = \frac{M}{mass}$$

$$I_v = \frac{M}{volume}$$

where M = magnetic moment.

Accordingly

$$\chi_m = \frac{M}{mass\ H} \qquad I$$

$$\chi_v = \frac{M}{vol\ H} \qquad II$$

Dividing equation I by equation II we have

$$\frac{\chi_m}{\chi_v} = \frac{vol}{mass} = \frac{1}{d}$$

Hence:

mass susceptibility = $\frac{\text{volume susceptibility}}{\text{density}}$.

The method used in this work was an application of the Faraday principle, in which the magnetic susceptibility was obtained by measuring the force exerted on a body when placed in a non uniform magnetic field. This force among other things is proportional to the field and its rate of variation, $H \frac{dH}{dx}$, and is a maximum when this product is a maximum. This maximum occurs at two places in the field, lying on the perpendicular bisector of the axix of the gap as shown in Fig. I.

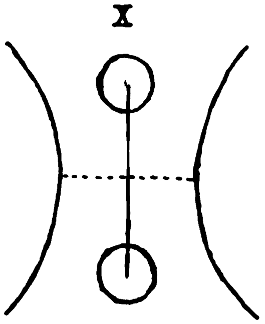

Fig. I.

Theory of Method.

Drude in "Die Physik des Aethers" has shown that the X component of the force upon a specimen of mass m placed in a field of strength H, as is shown by Figure I, is given by the expression

$$F_x = m \cdot \chi \cdot H \frac{dH}{dx} \qquad 111$$

where H = Field strength

χ = Mass susceptibility

$\frac{dH}{dx}$ = Rate of variation of magnetic field in the direction x

m = Mass.

If the same field is used and the force is measured with the specimen always in the same position, $H \frac{dH}{dx}$ is a

constant and χ may be measured by determining F_x.

Accordingly

$$\chi = \frac{F_x}{m \cdot H \frac{dH}{dx}} = \frac{k\, F_x}{m} \qquad \text{IV}$$

where k is a constant of proportionality which may be determined by measuring the force on a specimen of known susceptibility placed at the same point in the field.

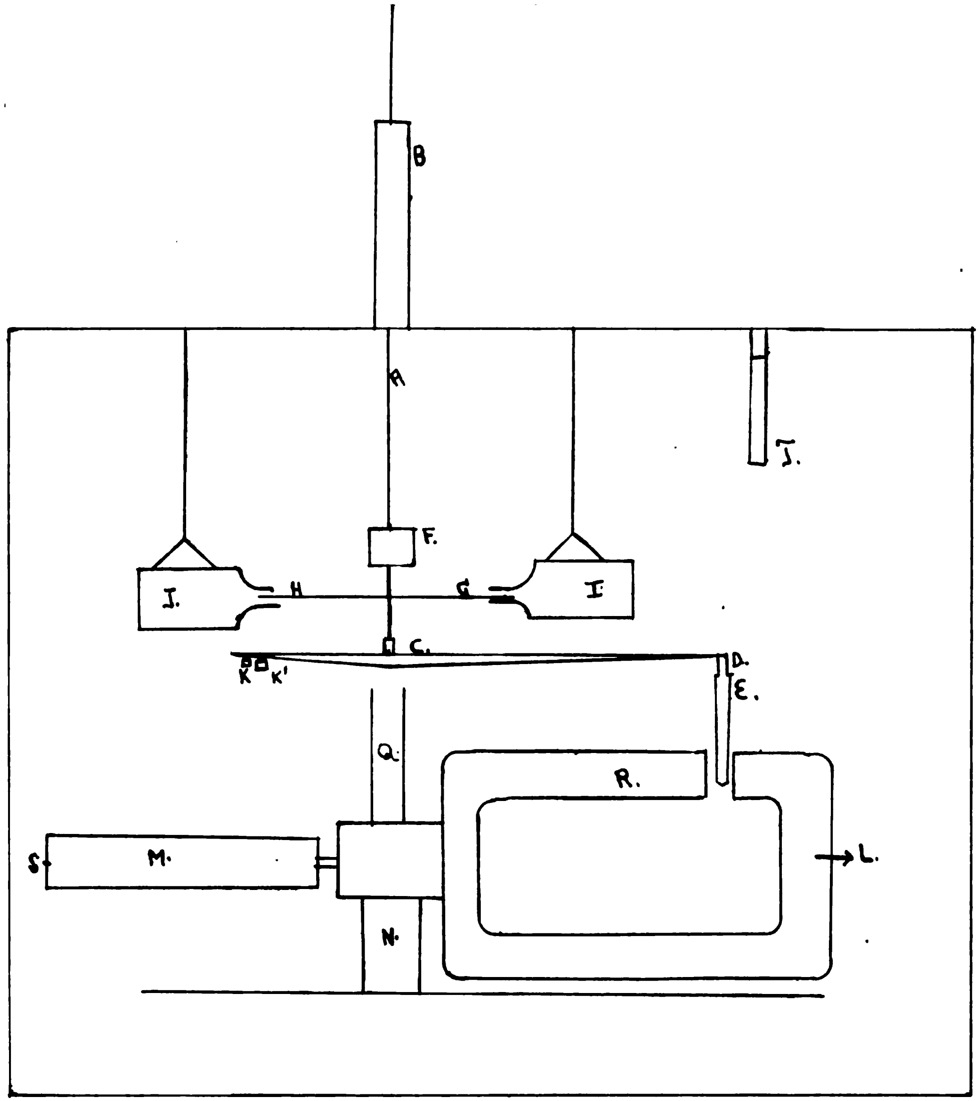

Fig III.

Apparatus.

To measure the force, F_x a modified form of the Curie[1] balance was used in which the torque produced by F_x was balanced against the torsion of a twisted wire.

The apparatus consisted of two separate systems, first, the torsion system and second, the moving magnet system, both of which were enclosed in a wooden case with a window of heavy plate glass and mounted as shown in Fig. II.

The torsion system was constructed of brass and aluminum, iron being used only in setting up the magnet system and in the auxiliary damping magnets. A torsion head B to which the suspended system was attached was placed perpendicular to the top of the case. The suspended system was joined to the torsion head by a No. 25 brass wire A. To the lower end of the wire was attached a horizontal beam c, one arm being 27.6 cm. in length, which combined minimum moment of inertia with maximum arm length, while the other balance arm was short and supported weights K and K', combining sensibility with short period. The end of the long lever arm was bent through an angle of 90 degrees and a ground glass stopper was waxed to it in such a manner that the specimen tube E could be fitted over it. In this way evaporation was prevented and a means afforded for supporting the specimen in the desired part of the field. To the upper part of the lever was attached a mirror F and a pair of damping vanes G and H, which swing freely between the poles of two permanent magnets I and J.

(1). Jour. de Phys. Vol. 7--p. 262. 1898.

The moving magnet system consisted of a permament magnet R, made of tungsten steel specially prepared for this purpose. Opposite the magnet was attached a heavy iron counterpoise M, and all was mounted on a fine conical spectrometer bearing N. The magnet was specially designed and built in the form of a rectangle with the poles O and P symmetrical and so arranged as to produce a uniformly varying field.

The magnet was so arranged that it could be rotated about a vertical axis Q, which coincided with the axis of the torsion system. This rotation was affected by means of fine copper wires attached to the extremities of the magnet at L, and its counterpoise at S. These wires were brought through the case and attached to a slow motion disk immediately in front whose purpose was to provide a slow and continuous motion of the interpolar gap.

The operation of the apparatus may be explained in the following way. Let the specimen which we will suppose to be placed in its equilibrium position that is, in the central part of the field, and the magnet so set that there is no twist in the torsion wire. If the magnet is slowly rotated in a given direction, the specimen will be drawn in the same direction, moving out of the field of the magnet. The specimen will continue to follow the magnet until it has reached the point in the field for which $\frac{HdH}{dx}$ is a maximum, after which it will return toward its zero position with a further rotation of the magnet. By observing the maximum deflection as the magnet is slowly rotated the pull on the specimen is obtained for the point in the field which we have selected.

The suspended or torsional system was arranged so that it could be raised or lowered in such a way that the volume of the tube containing the specimen could be placed in the most symmetrical part of the field. A Thermometer, T, was placed inside the case as near the specimen as convenient, and temperature changes could be estimated to .01 degree centigrade.

The telescope and scale for observing the deflection was placed immediately in front of the torsional system at a distance of eight feet. In addition to this an auxiliary telescope was used to locate the specimen in the symmetrical part of the interpolar gap.

As pointed out previously, the method assumes that the specimen under test is always placed in the same position in the field. The particular point chosen for this purpose was that in which the product $H \frac{dH}{dx}$ is a maximum since this combines maximum sensibility with ease of location. In using the apparatus the method employed was to slowly rotate the magnet and the maximum deflection of the torsional system was noted by means of the telescope and scale. When this deflection is a maximum the specimen is obviously at the desired point in the field.

Manipulation.

Cleaning.

The cleaning of the specimen tube and pipette used for filling, was a very important part of the procedure. The tube was first washed with distilled water and then rinsed with pure alcohol, after which, it was again rinsed with ether,

and finally rinsed and dried by means of a warmed air blast.

Filling.

It was necessary to take great care in filling for if too much of the liquid were lowered into the tube so that some had to be removed there was a film left on the sides due to cohesion. To avoid this effect a small pipette was used. A clamp holding the specimen at right angles so that it could be raised or lowered was used, thus preventing contact of the pipette with the sides of the tube.

Weighing.

For weighing, a Sartorims balance was used. The mass of the specimen was obtained by subtracting the weight of bottle and stopper from the combined weight of specimen and container.

Position in the field.

Angular adjustment or parallelism between the pole surfaces and the walls of the tube was made by adjusting the weights on the short lever arm of the balance beam. The lining up telescope was also used in testing for parallelism.

Measurements.

Deflections were measured from the position of one maximum twist to the position of the opposite maximum twist. The standard solutions were paramagnetic, that is, substances which were attracted toward the stronger part of the field, or the middle of the gap. The Esters were diamagnetic, or solutions that were repelled towards the weakest part of the field. The procedure used in detecting the susceptibilities of the para-

magnetic solutions was to bring the polar gap up from one side and to continue the motion, the specimen following the field until the maximum twist equalled the magnetic pull and the specimen started to return in the other direction. The reading of the greatest deflection was then recorded. Then the magnet was swung in the opposite direction until the maximum twist again equalled the magnetic pull. With the diamagnetic substances, the polar gap was brought up from one side and the specimen was repelled until the maximum twist equalled the magnetic repulsion, and the specimen started to return in the opposite direction. This maximum deflection was likewise recorded.

The pull due to the empty tube was negative which, since the pull due to the standard solutions was positive, had to be subtracted from the pull due to the tube plus the specimen. This then, gave the pull due to the specimen above.

Temperature Readings.

Curie's law of the inverse proportionality of temperature with the susceptibility was assumed in reducing the values of the susceptibility to any specified temperature, the temperature used being the absolute temperature. Since about five minutes were required to take the readings for each specimen, the reading of temperature was taken between the readings of the maximum deflection in one direction and the reading for the maximum deflection in the opposite direction. Thus we get an average value for the temperature for that particular reading.

Esters.

Esters may be defined as those substances which are formed by the union of alcohols and acids with the elimination of water[1].

The general equation for an Ester is

$$R_1\ C\ O\ O\ R_2$$

where R_1 and R_2 are alkyl radicals which may be alike or different. These are Esters of the parafin hydrocarbon series. The Esters for which the magnetic susceptibility has here been determined were chemically purified by Professor Malthews of the Chemistry Department. The materials used were the Kahlbaum highest purity compounds. The purification consisted of fractional distillation under a certain definite pressure, ussually 760 m. m., and only those fractions were used in which the greatest amount of liquid came over within a definite range of temperature.

Standardization.

As pointed out in Equation IV the measurement of the susceptibility χ is reduced to a measurement of the force F_x exerted upon the specimen when placed in the chosen point in the field. Since the torque due to the force F_x is balanced by the restoring torque of the suspending wire, F_x is proportional to deflection d, measured by the telescope and scale. We may accordingly write

$$\chi = \frac{Kd}{m} = K_2 d$$

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(1). Dictionary of Applied Chemistry--Thorpe p. 348.

where K_2 is a constant representing the susceptibility per unit deflection per gram mass. The constant K_2 was determined by measuring the deflections produced by using solutions of known susceptibility. For this purpose three standard solutions $Ni(No_3)_2$, $Co(NO_3)_2$, $Co(SO_4)$, whose susceptibilities has been carefully determined by Professor Terry, were employed. The data for this standardization is shown in Table I and the results for K_2 are summed up in Table II.

Table I

Data	Cobalt Nitrate	Nickel Nitrate	Cobalt Sulphate
No. of Observations	6	5	10
Deflection to Right	27.7 cm.	20.2 cm.	11.13 cm.
Deflection to Left	28.9 "	21.04 "	11.285 "
Total Deflection	56.66 "	41.24 "	22.415 "
Deflec. for diam. of tube	.35 "	.35 "	.35 "
Corrected Deflection	57.01 "	41.59 "	22.76 "
Mass of tube plus specimen	40.0124 gm.	41.232 gm.	40.841 gm.
Mass of tube	39.6244 gm.	39.625 "	39.625 "
Mass of specimen	1.388 "	1.607 "	1.216 "
Deflection per unit mass	41.09 cm.	25.81 cm.	18.71 cm.
Mean Temperature	20.276°	21.186°	19.38°
Deflection corrected to 20° C.	41,108 cm.	25.91 cm.	18.67 cm.

Susceptibilities of standard solutions.

Cobalt Nitrate	16.84×10^{-6}
Cobalt Sulphate	7.593×10^{-6}
Nickel Nitrate	1.052×10^{-6}

By use of these constants we may reduce deflections to susceptibility values as follows.

Table II.

	$\chi\ 10^{-6}$	Deflection	K_2
Cobalt Nitrate	16.84	41.108 cm.	4.096
Cobalt Sulphate	75.93	18.67 "	4.066
Nickel Nitrate	105.2	25.91 "	4.060

Thus the mean value of K_2 is (4.074) (10^{-6}) which is used in this thesis as the susceptibility constant of the system.

The method of recording and computing data for any given substance is illustrated in Table III, and the results for the remaining twelve Esters are condensed and tabulated in Table IV.

In Table V we have a summary of the various physical properties, so far as they have been determined, of the group of Esters whose susceptibilities have been studied in this work.

Table III.

Ethyl Propionate B. P. 97.5--97.75° **Pressure 760 m. m.**

Deflection Right	Deflection Left	Total Deflection	Temp.
cm.	cm.	cm.	C°
.9	1.0	1.9	23.05
.9	.9	1.8	23.15
.9	.9	1.8	23.15
.9	.9	1.8	23.15
.9	.9	1.8	23.15
.9	.9	1.8	23.10
.9	.9	1.8	23.10
.8	.9	1.7	23.10
.9	.9	1.8	23.05
.9	.9	1.8	23.05
Mean Diamagnetism		1.8	23.105
Correction for Diamagnetism of Tube		.35	273.
		1.45 cm.	296.105°
			Abs. Temp.

Mass of Tube plus Specimen	40.5692 gm.
Mass of Tube	39.6250 "
Mass of Specimen	.9442 "

Deflection unit mass at 20° C = 1.546 cm.

Whence $\chi = (1.546)(4.074 . 10^{-6}) = 6.2984 . 10^{-6}$.

Table IV.

Data:

Specimen	No. Of Obs.	Deflec. Rt. cm.	Deflec. Left. cm.	Total Deflec. cm.	Diam. of Tube cm.	Correc. Deflec cm.
Ethyl Propionate $C2H_5CO_2C_2H_5$	10	.89	.91	1.80	.35	1.45
Isobutyl Formate $HCO_2C_4H_9$	10	1.01	.955	1.965	.35	1.615
Propyl Alcohol $CH_3CH_2CH_2OH$	10	1.155	1.1	2.255	.35	1.905
Propel Propionate $C_2H_5CO_2C_3H_7$	10	1.03	1.00	2.03	.35	1.68
Isoamyl Formate HCO_2C_5H	10	.945	.970	1.915	.35	1.565
Isobutyl Acetate $C_2H_3O_2C_4H_9$	10	.97	1.01	1.98	.35	1.65
Heptane $CH3(CH2)5CH_3$	10	1.035	.985	2.01	.35	1.66
Propyl Acetate $CH_3CO_2C_3H_7$	10	1.057	1.00	2.057	.35	1.707
Ethyl Butyrate $C_3H_7CO_2C_2H_5$	10	1.020	1.02	2.045	.35	1.695
Acetone CH_3COCH_3	11	.96	.983	1.95	.35	1.60
Pyrdine C_6H_5N	10	1.13	1.195	2.325	.35	1.975
Benzene C_6H_6	10	1.1	1.125	2.23	.35	1.88

Table IV Continued.

Data:

Specimen	Mass of Tube & Spec. gm.	Mass of Tube. gm.	Mass of Spec. gm.	Deflec. Unit Mass cm.	Mean Temp. C°.	Defl. Correc. to 20° C.	$\chi 10^6$
Ethyl Propionate	40.5692	39.6250	.9442	1.53	23.10°	1.546	6.298
Isobutyl Formate	40.5590	39.6250	.9340	1.72	22.825°	1.736	7.082
Propyl Alcoohol	40.5700	39.6250	.9450	2.01	23.265°	2.035	8.2905
Propel Porpionate	40.6450	39.6250	1.020	1.64	18.235°	1.838	7.489
Isoamyl Formate	40.6250	39.6250	1.00	1.565	17,346°	1.5508	6,317
Isobutyl Acetate	40.6164	39.6250	.9914	1.64	18.19°	1.633	6.652
Heptane	40.4144	39.6250	.7894	2.12	18.45°	2.108	8.587
Propyl Acetate	40.6514	39.6250	1.0264	1.66	18.515°	1.685	6.864
Ethyl Butyrate	40.6004	39.6250	.9754	1.73	18.875°	1.723	7.019
Acetone	40.5492	39.6250	.9242	1.73	21.98°	1.741	7.092
Pyrdine	40.7804	39.6250	1.1554	1.709	22.715°	1.724	7.026
Benzene	40.5948	39.6250	.9698	1.909	22.753°	1.9303	7.864

Table V.

Properties of the Esters Studied.

Specimen	Molecular Weight	Specific Gravity	Boiling Point	Soluble in	Compressibility $B\ 10^6$
Ethyl Propionate	102.08	.8965	97.5-97.75°	H_2O. Al. Ether	78.8
Isobutyl Formate	102.08	$.9049\frac{3}{4}$	96.50-96.75°	H_2O	______
Propyl Alcohol	60.06	$.8035\ \frac{20}{4}$	96.24-96.30°	H_2O. Al. Ether	71.2
Propyl Propionate	116.10	$.8885^{13}$	121-121.25°	SS in H_2O Al. Ether.	______
Isoamyl Formate	116.10	$.8944\frac{3}{4}$	121.75-122°	Alcohol	72.8
Isobutyl Acetate	116.10	.89210/4	115 - 115.5°	H_2O. Al. Ether	78.6
Heptane	100.13	.7019 0/4	98.4°	Al. Ether	______
Propyl Acetate	102.05	.8908 8/4	98-98.5°	H_2O. Al. Ether	
Ethyl Butyrate	116.10	$.8978^{18}$	120-120.5°	SS in H_2O Al. Eth.	76.9
Acetone	58.05	$.7970\ \frac{15}{4}$	55.75-55.80°	Al. Eth.	______
Pyridine	79.08	$.9779\ \frac{25}{4}$	115.20°	H_2O. Eth.	______
Benzene	78.05	$.8799\ \frac{20}{4}$	80.20°	H_2O Al. Ether.	______

Table V Continued.

Specimen	Pressure under which sol. were distilled.	Surface Tension	Heat of Vap. Cal/gm.	Susceptibility $\chi 10^6$
Ethyl Propionate	760 mm.	23.32	79.3	6.29
Isobutyl Formate	743.5	23.37	81.5	7.08
Propyl Alcohol	744.9	24.23	——	8.29
Propyl Propionate	760	——	——	7.48
Isoamyl Formate	739.6	24.58	82.1	6.31
Isobutyl Acetate	739.2	23.62	73.2	6.65
Heptane	760	——	——	8.58
Propyl Acetate	731	24.00	81.1	6.86
Ethyl Butyrate	760	24.44	72.8	7.01
Acetone	760	——	——	7.09
Pyridine	——	——	——	7.02
Benzene	——	28.62	94.2	7.86

Conclusion.

The results of these experiments lead us to conclude that there is no direct relation between the magnetic susceptibility of these Esters and the other known properties.

Take, for instance, Ethyl Propionate whose susceptibility is 6.29, surface tension 23.32, Propyl Alcohol having a susceptibility of 8.25 and surface tension of 24.23, compare these with Isoamyl Formate whose susceptibility has an intermediate value but which has a higher surface tension than either of the other solutions, and we find that there is no correlation between susceptibility and surface tension.

Compare similarly Ethyl Propionate, Propel Propionate, and Heptane whose susceptibilities are respectively 6.29, 7.48 and 8.58. Propyl Propionate which has an intermediate susceptibility, has the highest molecular weight; Heptane has the greatest susceptibility and has the lowest molecular weight; Ethyl Propionate has the smallest susceptibility and has an intermediate value for its molecular weight,

Likewise by comparing susceptibilities with chemical composition of the solutions, we do not find any correlation. Hence, we must conclude that there is no direct relation between the magnetic property of these Esters and their other determined properties.

Approved by Earle M. Terry

March 21 1916.

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